B.5 HELIOPHYSICS LIVING WITH A STAR SCIENCE

NOTICE: Amended February 26, 2021. This amendment releases the final text for this program element, which had been listed as "TBD". Step-1 proposals are due September 8, 2021, and Step-2 proposals are due November 18, 2021.

The description of the Proposed Contribution to the Focused Science Team effort has been moved from the NSPIRES cover pages to a section following the Science/Technical/Management section and is discussed in Section 6.3.2.

1. Scope of Program

The Living With a Star (LWS) Program emphasizes the science necessary to understand those aspects of the Sun and Earth's space environment that affect life and society. The ultimate goal of the LWS Program is to provide a scientific understanding of the system that leads to predictive capability of the space environment conditions at Earth, other planetary systems, and in the interplanetary medium. Every year the LWS Program solicits Focused Science Topics (FSTs) that address some part of this goal. This year's FSTs are described in Sections 1.2 and 2-5 below.

This goal poses two great challenges for the LWS program. First, the program seeks to address large-scale problems that cross discipline and technique boundaries (e.g., data analysis, theory, modeling, etc.); and second, the program will identify how this new understanding has a direct impact on life and society. Over time, the Targeted Investigations have provided advances in scientific understanding that address these challenges.

LWS is a component of the Heliophysics Research Program and proposers interested in this program element should read B.1 The Heliophysics Research Program Overview, for Heliophysics-specific requirements. Defaults for all ROSES elements are found in the ROSES *Summary of Solicitation* and for all NASA solicitations in the *Guidebook* for *Proposers* (https://www.nasa.gov/offices/ocfo/gpc/regulations_and_guidance). The order of precedence is the following: This document (B.5) followed by B.1, followed by the ROSES *Summary of Solicitation*, and the *Proposer's Guidebook*. Proposers should review all of these resources to ensure compliance with Program requirements.

1.1 General LWS Goals and Background

The LWS program goals are to:

1. Understand how the Sun varies and what drives solar variability.
2. Understand how the Earth and planetary systems respond to dynamic external and internal drivers.
3. Understand how and in what ways dynamic space environments affect human and robotic exploration activities.

The LWS Program seeks to make progress in understanding the complex Heliophysics system, focusing on the fundamental science of the most critical interconnections. Further information on the LWS Program can be found at the LWS website (http://lwstrt.gsfc.nasa.gov/). The LWS Science program maintains a strategy with three basic components, namely, Strategic Capabilities, Targeted Investigations, and Cross-

Disciplinary Infrastructure Building programs. Only the Targeted Investigations will be competed in this program element. Proposers interested in Strategic Capabilities should see program element B.6 Living With a Star Strategic Capabilities. Cross-Disciplinary Infrastructure Building may be competed in a separate future element. This year, an additional Living With a Star opportunity is available in B.18 LWS Tools and Methods.

Further background material concerning relevant research objectives can be found on the LWS website, and in the following documents:

- The LWS TR&T SDT Report (https://lwstrt.gsfc.nasa.gov/images/pdf/TRT_SDT_Report.pdf)
- The LWS *10-Year Vision Beyond 2015 Report* (http://lwstrt.gsfc.nasa.gov/images/pdf/LWS_10YrVision_Oct2015_Final.pdf)
- The Revised Strategic Science Areas (https://lwstrt.gsfc.nasa.gov/assets/docs/lpag/LPAG_EC_report_2019_12_31.pdf)
- The National Research Council Decadal Survey Report *Solar and Space Physics: A Science for a Technological Society* (http://www.nap.edu/openbook.php?record_id=13060).

1.2 Solicited Investigations

To be responsive, proposed investigations must have objectives suitable for one of the four following Focused Science Topics (FSTs). Detailed descriptions of each FST are given in Sections 2 – 5.

The FSTs solicited for proposals this year are as follows:

1) Impact of Terrestrial Weather on the Ionosphere – Thermosphere (described in Section 2);
2) Pathways of Cold Plasma through the Magnetosphere (described in Section 3);
3) Understanding the Large-Scale Evolution of the Solar Wind throughout the Heliosphere through the Solar Cycle (described in Section 4); and
4) Towards a Quantitative Description of the Magnetic Origins of the Corona and Inner Heliosphere (described in Section 5).

NASA desires a balance of research investigation techniques for each FST, including theory, modeling, data analysis, and simulations. This program element accepts proposals that lack a complete scientific study but instead describe a project that would enable or enhance the FST's activities (e.g., develop a data set or implement a model for use by the FST Team). Regardless of the project, all proposals must identify science questions responsive to the FST's goals that are addressed by the proposed work. FST teams will be formed from individual proposals that each address an aspect of the FST, and together attack the breadth of the FST (see Section 1.3 below).

A critical element in enhancing understanding and developing predictive capabilities is the determination of whether the model or data products being developed, and any associated simulations, are accurate and reliable. Consequently, a methodology for verification and validation of results, and quantification of uncertainty, is required as a key component of the proposed research. As mentioned below (Sections 2.4, 3.4, 4.4, or 5.4), all proposals must address data and model uncertainty. This is mentioned in

Section 3.13 of the *NASA Guidebook for Proposers*, which indicates that all proposals must address "sources of error and uncertainties and what effect they may have on the robustness of potential results and conclusions."

1.3 Focused Science Teams

The selected investigators will form a Focused Science Team and coordinate their research programs after selection of proposals. In order to foster the collaborations required to coordinate these team research efforts, one of the Principal Investigators (PIs) will serve as the Team Leader for the FST for which he/she proposed. The Team Leader will organize team meetings and will be responsible for producing a yearly report to NASA Headquarters describing team activities and progress in addition to the required annual progress report for their specific award.

Proposers wishing to serve as a Team Leader must state so in their proposal and must include a separate section describing their qualifications, interest, and approaches to team leadership (see Section 6.3.1). The selection of the Team Leader will be recommended by the LWS staff and made by the Heliophysics selecting official. Guidance for the team development process will be provided by NASA after selection of the Team Leader.

Past experience has shown that Focused Science Teams usually need a year to get organized since team members may not have worked together before, followed by another three years to make significant progress on the FST. Thus, the expected duration of FST awards is four years. While proposals with shorter duration are allowed, proposers are encouraged to propose up to four years to ensure maximum overlap between individual contributions to the team efforts. Selected proposals for periods of performance less than four years may be extended to four years at the discretion of the LWS Staff in order to maximize overlap with other FST Team members.

All proposers must include sufficient travel funds in their budgets to cover two team meetings per year. In an effort to leverage travel costs, one meeting per year may be held in conjunction with a major U.S. scientific meeting. Successful teams will participate in a Kickoff Workshop where the selected team members will meet and develop work plans for the anticipated period of performance, generally four (4) years, based on the requirements of the FST and the composition of the selected team.

1.4 Data Use in the LWS Program

This program element has policies on the use of data in proposals that expand upon and supersede those given in B.1, the Heliophysics Research Program Overview. Proposals to this program may only require for successful completion of the proposed project the use of data that is in a publicly available archive at no cost at least thirty (30) days prior to the Step-2 deadline. This applies to both space-based and ground-based observations, as well as any data products derived from them. Data products to be developed as part of a proposed study are permissible; only those existing in advance of Step-2 submission must satisfy the 30-day requirement. Any questions about whether a data set or data product qualifies as publicly available must be submitted to the Program Officer of the element at least ten (10) days before the Step-1 deadline.

After an award is made, projects may incorporate new data that becomes available at no cost in a public archive, provided that their use does not alter the goals and objectives of the selected proposal. Any planned changes in the data used must be described in the annual progress report submitted by the PI and approved by the LWS Program Scientist.

While the inclusion of useful ground-based observations is allowed, proposals are expected to incorporate space-based observations. Further, the Step-2 evaluation process (see Section 6.3.4) will include the consideration of the presence and importance of space-based or ground-based observations in the proposals. Regardless of the type of data that would be utilized in the proposed study, space-based, ground-based, or some combination, the proposal must clearly demonstrate why the proposed data set or data sets are sufficient to address the proposed goals and objectives.

2. FST #1: Impact of Terrestrial Weather on the Ionosphere – Thermosphere

2.1 FST #1 Target Description

Processes generated by terrestrial weather in the lower atmosphere (i.e., troposphere and stratosphere, altitudes less than ~50 km) are increasingly recognized by the research community as sources of variability in both the structure and composition of the ionosphere-thermosphere-mesosphere (ITM) region over a broad range of time scales. These processes can include but are not limited to: (1) upward propagating gravity waves generated by flow over orography, intense convection, or flow instability; (2) migrating and non-migrating tides produced by solar heating or latent heat release; (3) traveling planetary-scale waves related to resonant modes that are generated within the lower atmosphere. Observational studies have shown, and modeling studies have confirmed, that these and other processes related to specific terrestrial weather events (e.g., stratospheric sudden warmings, tropical cyclones, localized sources of intense orographic gravity waves or “hot spots”) can impact the short-term variability of the ITM. Furthermore, numerical simulations that include realistic lower atmospheric forcing indicate that the amount of variability produced within the ionosphere by these terrestrial sources can, at times, be comparable to the variability produced by external (i.e., solar) drivers of space weather. What is not yet clear are the specific pathways through which these and other lower atmospheric processes related to terrestrial weather can influence both short-term and mean-state variability of the ITM, nor has the degree of predictability of these processes been well defined.

This FST will target both observational and modeling studies that investigate ITM variability coupled to terrestrial weather. This topic is timely for two reasons: (1) modeling has advanced sufficiently to tackle the multi-faceted problem; (2) new data resources exist that allow for detailed model-data comparisons. Specifically, first-principles numerical models of the atmosphere extending from the surface to the exobase (~500 km altitude) are now available to investigate at sufficiently high resolution the mechanisms that contribute to ITM variability. Numerical simulations that incorporate lower atmosphere variability can support realistic investigations into the pathways coupling terrestrial weather inputs and the ITM, and the results can inform predictability of the geospace environment.

By investigating the pathways for energy flow from the lower atmosphere that affect the structure, composition and circulation of the ITM, this FST addresses Heliophysics Decadal Survey Key Science Goal 2, “Determine the dynamics and coupling of Earth’s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs”. This FST also addresses goal 4 of LWS 10 Year Vision Report: “Deliver understanding and predictive models of upper atmospheric and ionospheric responses to changes in solar electromagnetic radiation, and to coupling above and below”. Applicable LWS Strategic Science Areas are SSA-IV (Variability of the Geomagnetic Environment), SSA-V (Dynamics of the Global Ionosphere and Plasmasphere), SSA-VI (Localized Ionospheric Irregularities), and SSA-VII (Composition and Energetics of the Neutral Upper Atmosphere).

2.2 FST #1 Goals, Objectives, and Measures of Success

The overarching goal of this FST is to advance our fundamental scientific understanding of terrestrial weather’s impact on the ITM as well as enhance future space weather prediction capabilities. To address this goal, proposed investigations should include one or more of the following objectives:

- Identify and quantify the relative roles of the different processes related to terrestrial weather driving the ITM;
- Identify and quantify the wave sources, forcing and ITM response at different temporal and spatial scales;
- Investigate the role of non-linear wave mean-flow and wave-wave interactions in affecting the energy input to the ITM from terrestrial sources;
- Determine the time scales for predictability among the individual components of the ITM system in response to forcing from below associated with terrestrial weather.

Measures of success for the FST include, but are not limited to:

- Successful integration of theory, physics-based modeling, data assimilation, and innovative data analysis to provide a comprehensive assessment of the relative contributions to terrestrial weather’s impact on both regional and global ITM variability from specific sources (e.g., gravity waves, tides, planetary waves);
- Quantification of the predictability of terrestrial weather’s impact on the ITM from daily, seasonal, and longer time scales.

2.3 FST #1 Types of Investigations

In general, studies could include investigations that target different aspects of the physical mechanisms coupling lower atmospheric processes to the thermosphere, as well as processes coupling the neutral thermosphere and ionosphere. Specific investigations may include but are not limited to:

- correlation of ionospheric variability with known meteorological events (e.g., SSWs, the Madden-Julian Oscillation, tropical cyclones, gravity wave hotspots);
- longitudinal dependence of ionospheric variability due to combined effects of planetary waves and tides;
- generation of ionospheric instabilities related to specific terrestrial weather events;
- observation-driven investigations of ITM variability related to terrestrial weather using satellites and ground-based systems;
- interactions among planetary waves, tides, and gravity waves impacting the ITM.

Investigations within this FST may include theoretical, numerical, and data analysis methods that apply physics-based atmospheric and ionospheric models, new machine learning-based methods, and new data assimilation techniques to better understand wave sources and propagation.

Relevant observational sources for these studies may include new satellite-based observations of the ITM (e.g., GOLD, ICON, COSMIC2) as well as networks of ground-based instruments (GNSS receivers, ionosondes, radars, lidars and imagers); existing observations from Aura, Aqua, Terra, and TIMED satellites; and high-altitude meteorological analysis products based on data assimilation. Details of the data use policy are discussed in Section 1.4.

2.4 FST #1 Data and Model Uncertainty

In order to improve the usefulness of the results from this FST, all investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 6.3.4).

3. FST #2: Pathways of Cold Plasma through the Magnetosphere

3.1 FST #2 Target Description

Low-energy (< 1 keV) ions and electrons play significant roles in the magnetospheric system. While this plasma often dominates the number density and mass density of the magnetosphere, it is amongst the least characterized and understood plasma populations, particularly in the very cold < 20eV energy range, which has always been challenging to measure. Our knowledge of the composition and distribution function characteristics of this cold population is still limited, yet it is this population that plays a crucial controlling role in many magnetospheric processes – from the generation, amplification, damping and propagation of plasma waves that reside in the magnetosphere; to the wave-particle interaction processes that couple between other plasma populations: the ring current, the electron radiation belt, substorm-injected electrons, plasma-sheet ions, and plasma-sheet electrons. Mass-loading effects of this population can also alter dayside reconnection and thus influence solar-wind / magnetosphere coupling.

This FST targets two important plasma populations: the cold plasmasphere and its drainage plume; and the plasma cloak. Our knowledge of the refilling rates for the plasmasphere is still insufficient, while there are basic questions on the plasma cloak's source – where, when, and how much?

Both these populations may play an important role in the recirculation of the plasma into the magnetotail. There are outstanding questions on the recirculation pathways, and the resulting composition, spatial extend and density of these populations along the magnetopause boundary.

Further details on the composition and distribution function of the low-energy and very cold plasma would also allow new investigations on the role these populations play on other magnetospheric processes, including heating, loss and transport of this population itself.

This FST addresses the Decadal Survey Key Science Goal 2 (Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs). This FST further addresses two Key Questions for Future Study in the 2013 Decadal Survey Consensus Report: "How are plasmas produced, lost, and energized in the magnetosphere?" and "How does the ionosphere-thermosphere system regulate the flow of solar energy throughout geospace?" and several LWS Strategic Science Areas including SSA-IV (Variability of the Geomagnetic Environment) and SSA-V (Dynamics of the Global Ionosphere and Plasmasphere).

3.2 FST #2 Goals, Objectives, and Measures of Success

The main goal for this FST is to make significant progress towards understanding and predicting the complex feedback between ionospheric outflows and magnetospheric plasma on the coupling of the solar wind to the system. To address this goal, proposed investigations should include one or more of the following objectives:

- Provide a better understanding of plasma sources in the ionosphere: the refilling of the plasmasphere, and the origin of the warm plasma cloak; and to understand the factors controlling these sources;
- Investigation of the evolution of the plasmasphere and plasma cloak and the impact that it has on the magnetospheric system;
- Determination of recirculation of the low-energy plasmas from the dipolar region into the magnetotail, and the impact this may have on the magnetospheric system;
- Determination of the properties and controlling factors of the low-energy electron and ion populations on downstream magnetospheric processes.

Compared to the modeling of higher energy populations in the ring current and radiation belts the characterization, physics and dynamics of the cold plasma population requires further progress. Therefore, this FST specifically focuses on enhancing our understanding of the sources and distribution of this population in the magnetospheric system, and processes controlled by the cold plasma within the framework of LWS needs.

Measures of success for this FST include, but are not limited to studies that demonstrate:

- Understanding of cold plasma sources;
- Improved understanding of the impact of cold plasma on magnetospheric processes and the magnetospheric system; and

- Predictive capability of temporal, spatial, and spectral characteristics of the cold plasma population by using observations and existing models.

Magnetospheric research has seen a recent boon of observations (e.g., Van Allen Probes, Themis, Los Alamos Magnetospheric Plasma Analyzer(LANL-MPA), and MMS) and historic ones (e.g., FATS, Cluster, and Dynamics Explorer) that have greatly expanded the availability of high-quality data. First-principle and empirical models have also benefited from this unprecedented wealth of information against which their performance can be measured and improved.

3.3 FST #2 Types of Investigations

In general, studies could include investigations that target the physical understanding of plasma processes within, and affected by, the cold population; coordinated data and modeling studies between ionospheric, thermospheric, and magnetospheric researchers to understand plasma sources and their global evolution; and development of empirical / machine-learning models that can supplement the development of – and serve as comparison basis for – first-principle models for these populations.

These investigations include, but are not limited to the following types of studies:

- Efforts to improve models utilizing first-principle plasmasphere-refilling simulation capabilities, and efforts to test these simulations with magnetospheric spacecraft observations;
- Efforts to improve the characterization of cold plasma composition and distributions functions, through either data or modeling studies;
- Surveys of low-altitude and equatorial spacecraft measurements from multiple missions in coordination with global magnetospheric modeling; and
- Efforts to advance the self-consistent modeling of cold plasma processes and processes controlled by the cold plasma.

Investigations within this FST may include theoretical, numerical, and data analysis methods. Relevant observational sources for these studies include present-epoch spacecraft and ground-based observations, as well as historical records of proxy observations of the cold plasma population. Details of the data use policy are discussed in Section 1.4.

3.4 FST #2 Data and Model Uncertainty

In order to improve the usefulness of the results from this FST, all investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 6.3.4).

4. FST #3: Understanding the Large-Scale Evolution of the Solar Wind throughout the Heliosphere through the Solar Cycle

4.1 FST #3 Target Description

The solar wind is a high-speed flow of magnetized plasma that originates in the corona of the Sun, and moving outward, ultimately forms, fills and sustains the region of solar magnetic influence called the heliosphere. Understanding the evolution of the solar wind as it moves though the solar system requires an understanding of the numerous physical processes that drive and shape the plasma.

As a given parcel of plasma is released from the Sun with a range of initial velocities and moves outward from the corona, it transitions from subsonic to supersonic flow speeds. This plasma carries Alfvénic fluctuations that are damped out in the inner heliosphere. Slower plasma parcels lag faster ones, creating rarefactions in the flow. Similarly, faster parcels overtake slower ones and dynamically interact, creating compressions which can sharpen into shocks between 1 and 4 AU. These shocks dissipate as they move outward past 4 AU. Interstellar neutral particles, ionized by UV radiation, charge exchange or electron collisions further augment the plasma as they are picked up by the solar wind. By 20 – 30 AU these are responsible for plasma heating and ultimately the slowing of the solar wind from supersonic to subsonic speeds at the termination shock (80 – 100 AU). In the heliosheath, this subsonic plasma continues moving outward until it reaches the heliopause. The solar cycle drives changes to the details of these processes with an 11-year period.

Quantifying these processes and time-varying phenomena requires long duration, high quality measurements. Coronagraph images (LASCO, STEREO) have been made during the past two solar cycles, as have EUV measurements of the solar corona (e.g., EIT, Hinode, AIA, STEREO). YOHKOH, Hinode and GOES (to name a few) have provided x-ray observations of the corona for three solar cycles. The solar photosphere's magnetic field has also been measured for the last four solar cycles by KPVT, MDI, HMI and others. *In situ* observations from ACE, Wind and STEREO and other platforms are available for the last two solar cycles. The Ulysses mission observed the Sun for nearly two solar cycles from a unique, out-of-ecliptic vantage point. Solar Orbiter will provide high-resolution inner-heliosphere observations, and Parker Solar Probe will soon visit the Alfvén point to observe the solar wind's transition from subsonic to supersonic flow. In addition, the OMNI database provides a long-term, robust set of observations of the Sun. These and other observations provide a broad range of information which supports the study of the impact of the solar cycle on solar wind variations as well as solar transients and variability.

These inner-heliosphere observations can be combined with measurements from spacecraft in other, more distant environments (e.g., New Horizons, Voyager and Juno) to specifically address the evolution of the global structure of the heliosphere. Remote observations of heliospheric phenomena from IBEX allow the study of large-scale processes. This collection provides an opportunity to characterize the processes that drive and describe the plasma and magnetic environment of the slowly varying heliosphere.

This FST primarily addresses two Key Science Goals of the 2013 Decadal Survey: #1 "Determine the origins of the Sun's activity and predict the variations in the space environment," and #3 "Determine the interaction of the Sun with the solar system and the interstellar medium." In addition, it supports several LWS Strategic Science Areas including SSA-I (Origins and Variability of Global Solar Processes), SSA-II (Solar Eruptive and Transient Heliospheric Phenomena), and SSA-III (Acceleration and Transport of Solar Energetic Particles).

4.2 FST #3 Goals, Objectives, and Measures of Success

The main goals of this FST are to understand (1) the physical processes driving the formation and propagation of solar-wind structures throughout the heliosphere and their variability with the solar cycle and (2) how the solar magnetic field and coronal structure determine the plasma and magnetic-field conditions in the inner heliosphere throughout the solar cycle.

To address these goals, investigations should include one or more of the following objectives:

- Utilize long-term measurements to quantify how the solar cycle impacts the *in situ* plasma and magnetic field of the inner heliosphere;
- Investigate the radial evolution of wave activity, turbulence, dynamic interactions, and shock formation;
- Determine how multiple solar wind structures (slow and fast streams and CMEs) merge to form Merged Interaction Regions (MIRs) and Global Merged Interaction regions (GMIRs); and
- Investigate how the solar wind and interstellar pickup ions interact to modify shocks in the outer heliosphere and form both the heliosheath and heliopause boundaries.

Measures of success for this FST include, but are not limited to the demonstration of:

- Understanding and quantification of processes responsible for the evolution of solar wind structures;
- Understanding and quantification of the impact of solar cycle variability on solar wind structures in the inner heliosphere; and
- Understanding and quantification of key interactions and processes that modify structures in the outer heliosphere.

4.3 FST #3 Types of Investigations

There are a large number of physical processes acting under a variety of conditions, with varying drivers and their associated large time lags. Consequently, a more holistic approach will be necessary to gain an understanding of the heliosphere as a system.

Types of investigations include but are not limited to:

- Quantification of the impact of the solar cycle on in situ plasma, magnetic field, and energetic particle observations utilizing long-term measurements;
- Enhanced modeling studies by incorporating diverse observations;
- Combination of multiple instrument measurements into a single “super-instrument” with a homogeneous dataset spanning multiple cycles of observations; and
- Application of AI/ML techniques to connect diverse large data sets and to build empirical models of the heliosphere.

4.4 FST #3 Data and Model Uncertainty

In order to improve the usefulness of the results from this FST, all investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 6.3.4).

5. FST #4: Towards a Quantitative Description of the Magnetic Origins of the Corona and Inner Heliosphere

5.1 FST #4 Target Description

Achieving a quantitative understanding of how the Sun influences the heliosphere and Earth's space environment requires the ability to quantitatively describe, and ultimately predict, the magnetic field in both the local and the global solar corona and the inner heliosphere. The magnetic field at the solar photosphere is a crucial input to both empirical and physics-based models of the corona and solar wind. Current global models of the solar corona and inner heliosphere frequently use global magnetic maps derived from photospheric magnetograms that are available from a number of ground- and space-based observatories, including, but not limited to: GONG, SOLIS, SOHO/MDI, and SDO/HMI.

However, a number of issues make it difficult to use these various data to their fullest extent. For instance, difficult-to-correct instrumental effects such as zero-point offsets in magnetograms mean that measurements often differ substantially from one instrument to the next, making it difficult to generate global maps of the Sun. The fields in the polar regions are poorly observed from Earth or from spacecraft in the ecliptic plane, and line-of-sight (LOS) magnetograms (rather than the potentially available vector measurements) are often used to reconstruct the radial photospheric field. The evolution of the magnetic field and plasma from the photosphere through the chromosphere and corona is not well understood, leading to the use of empirical approaches to describe coronal heating and solar wind acceleration. Finally, current models do not take full advantage of key information on the magnetic field provided indirectly by multi-viewpoint coronagraph observations or directly by multi-point *in situ* measurements in the inner heliosphere. These issues result in a research 'bottleneck' that hinders the reliability of global coronal models, which in turn drive models of the heliosphere.

In addition to large-scale global phenomena, the photosphere is the source of vital small scale magnetic flux elements that drive and propagate sub-arcsecond dynamics in the solar atmosphere. Bridging the gap between the full-disk magnetograms mentioned above and high-resolution photospheric observations from instruments such as Hinode/SOT, IRIS, and Solar Orbiter is critical to improving the physical understanding underlying subgrid-scale models.

This is a timely topic, considering that the Parker Solar Probe mission is now measuring and observing the solar wind near its source region and Solar Orbiter is conducting high-resolution observations of the Sun and the inner heliosphere (other observations may become available from future sources such as DKIST and PUNCH when they become operational, but proposals to this solicitation cannot rely on these data). A full understanding of these measurements requires accurate coronal and heliospheric models of the magnetic field.

This topic also directly addresses Key Science Goal 1 of the Decadal Survey, namely to "Determine the origins of the Sun's activity and predict the variations in the space environment." Improving the fidelity and calibration of photospheric magnetic fields are critical for achieving many of the Solar and Space Physics Decadal Challenges. Namely, "SHP-1 Understand how the Sun generates the quasi-cyclical magnetic field that extends throughout the heliosphere" requires an accurate measurement of the solar magnetic field as a function of time; "SHP-2 Determine how the Sun's magnetism creates its hot, dynamic atmosphere" requires knowledge of the solar magnetic field, which currently is most accurately measured by these photospheric observations, and "SHP-3 Determine how magnetic energy is stored and explosively released and how the resultant disturbances propagate through the heliosphere" again requires detailed and accurate knowledge of the photospheric magnetic field evolution. This FST addresses several LWS Strategic Science Areas, including SSA-I (Origins and Variability of Global Solar Processes), SSA-II (Solar Eruptive and Transient Heliospheric Phenomena), SSA-IV (Variability of the Geomagnetic Environment), SSA-VIII (Radiation and Particle Environment from Near Earth to Deep Space), and SSA-X (Solar Impacts on Climate).

5.2 FST #4 Goals, Objectives, and Measures of Success

The primary goal of this FST is to obtain a quantitative understanding of the structure and evolution of the magnetic field from the solar photosphere to the inner heliosphere. To address this goal, proposed investigations should include one or more of the following objectives:

- Understand how plasma processes or time-dependent evolution lead to global non-potentiality;
- Understand how magnetic connectivity evolves from the photosphere to the inner heliosphere; and
- Understand how the magnetic field drives coronal and heliospheric structure and dynamics.

Measures of success for this FST include, but are not limited to:

- Demonstration of an understanding of the magnetic connectivity from the Sun to Earth, Mars, Moon and other points in the inner heliosphere;
- Improved modeling of the solar corona at altitudes below the Alfvénic point; and
- Production of time sequences of global magnetic field maps that smoothly assimilate new data (including far-side measurements) and are made available to drive global models (research and operational) to provide a real-time forecast of the state of the heliosphere.

The successful outcome of this FST will improve, if not remove, an important obstacle in our ability to predict the state of the inner heliosphere. The results will impact across a wide swath of the user community, including space exploration and satellite operations.

5.3 FST #4 Types of Investigations

The photospheric magnetic field influences the formation and evolution of coronal hole boundaries, the solar wind, and the interplanetary magnetic field, but there is not a one-to-one relationship. Theoretical, numerical, and data analysis methods are all required to address the science goal and objectives of this FST. In particular, theoretical or modeling investigations linking coronal and heliospheric structures to surface field distributions would synergize well with the data-oriented projects outlined in this FST.

Types of Investigations include, but are not limited to:

- Development of methodologies to improve the cross-calibration of magnetic field measurements from different observatories.
- Development of methodologies to account for poorly observed polar field contributions and far-side field contributions to the global magnetic field structure. Such investigations could include, for example, exploration of the use of coronal or solar wind models and observations to improve and inform surface-field maps when data are not available or uncertain (e.g. at the poles) or as a method of validation.
- Studies that explore novel or little-used datasets (e.g., chromospheric or coronal magnetic fields from optical/infrared or radio techniques), advanced inversion algorithms (e.g., non-force-free approaches), machine learning approaches, and data assimilation techniques.
- Physics-based and statistical studies connecting surface-field distributions to coronal and heliospheric structure.
- Development of methodologies for 3D magnetic field reconstruction using multi-viewpoint photospheric magnetograms and EUV (or other) observations of the corona.
- Development of methodologies for incorporating vector magnetic fields, in addition to fields derived from LOS observations, into radial field maps.

5.4 FST #4 Data and Model Uncertainty

In order to improve the usefulness of the results from this FST, all investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 6.3.4).

6. Submission and Evaluation Guidelines

Each PI, or the Science PI if applicable, is allowed to submit one and only one proposal to this program element. The PI (or Science PI) must invest at least 20% of their time per year to the investigation in order to adequately ensure the conduct of the investigation.

In addition to the general requirements and restrictions (e.g., in Table 1 of the *ROSES-2021 Summary of Solicitation* and in B.1 Heliophysics Research Program Overview) this program element has specific compliance constraints for both format (e.g., Sections 6.2.1 and 6.3.1) and content, e.g., involving data (see Sections 1.4 and 6.3.4). These compliance rules ensure fairness and are enforced strictly by the Heliophysics Division.

Proposals that are deemed noncompliant may be returned without review or declined following review if violations are found during the evaluation process.

6.1 Two-Step Submission Process

To provide adequate notice to potential reviewers, this program uses a two-step proposal submission process. The overall description of a two-step process can be found in Section IV(b)vii of the *ROSES-2021 Summary of Solicitation*.

In the two-step process a Step-1 proposal is required. Because potential reviewers are solicited based on the Step-1 proposal, investigators cannot be changed between the Step-1 and Step-2 proposals, unless prior approval is obtained from the Program Officer of the element. The title and broad science goals of the proposal cannot be changed such that they would significantly affect the scientific or technical expertise required to properly evaluate a proposal. Changes in a proposal that impact the review will result in a proposal being declared noncompliant.

6.2 Step-1 Proposals

A Step-1 proposal is required and must be submitted electronically by the Step-1 due date given in Tables 2 and 3 of the *ROSES-2021 Summary of Solicitation*. The Step-1 proposal must be submitted by an Authorized Organizational Representative (AOR) from the PI institution. No budget or other uploaded files are required. Step-1 proposals will be checked for compliance, but they will not be evaluated. Only proposers who submit a Step-1 proposal and who are invited are eligible to submit a Step-2 (full) proposal.

Submission of a Step-1 proposal does not obligate the offerors to submit a Step-2 (full) proposal.

6.2.1 *Step-1 Proposal Format*

The Step-1 proposal is restricted to a 4,000-character Proposal Summary text box on the NSPIRES web interface cover pages. It must include the following information:

- A description of the science goals and objectives to be addressed by the proposal;
- A brief description of the methodology to be used to address the goals and objectives; and
- A brief description of the relevance of the proposed study to the scientific objectives of the FST, and the potential contributions of the proposed study to the Focused Science Team's effort.

No PDF attachment is required or permitted for Step-1 proposal submission. Proposers will be notified by NSPIRES whether they are invited to submit their Step-2 proposals. Proposers are strongly encouraged to provide names and contact information of up to five experts qualified to review their proposal. These experts must not be from the institutions of the PI or Co-Is. This information can be supplied in response to NSPIRES cover page questions at the time of submission of the Step-1 proposal.

6.2.2 *Step-1 Compliance Criteria*

Step-1 proposals may be declared noncompliant if they fail to meet the submission guidelines or if they are outside the scope of either the LWS Science program or the specific FST selected by the proposer. PIs of noncompliant proposals will not be invited through NSPIRES to submit the associated Step-2 proposal and will be notified through NSPIRES to this effect.

6.3 Step-2 Proposals

A Step-2 (full) proposal must be submitted electronically by the Step-2 due date given in Tables 2 and 3 of the *ROSES-2021 Summary of Solicitation*. The Step-2 proposal must be submitted by an Authorized Organizational Representative (AOR) from the PI institution. A budget and other specified information is required.

Only proposers who submit a Step-1 proposal and who are invited are eligible to submit a Step-2 (full) proposal. Proposers that have received a noncompliance letter in response to their Step-1 proposal are not eligible to submit a Step-2 proposal.

6.3.1 *Step-2 Proposal Format*

All proposals submitted to ROSES must strictly conform to the formatting instructions specified in the *ROSES-2021 Summary of Solicitation* except were superseded by the requirements in this program element. Proposals that violate these instructions may be returned without review or declined following review if violations are found during the evaluation process.

Proposals are restricted to fifteen (15) pages for the Science/Technical/Management section. Proposals for Team Leader additionally must describe the proposed team leader activities in a separate section, not to exceed one (1) page in length, entitled "Proposed Team Leader Contribution" (see Section 1.3). When included, this section should follow the section on "Proposed Contribution to the Focused Science Team Effort" described in Section 6.3.2. This section on Team Leader Contribution does not count against the 15-page limit for the Science/Technical/Management section.

Proposals must include a Data Management Plan, as described in Section 1.5 of B.1, the Heliophysics Research Program Overview. The Data Management Plan must be placed in a separate section, not to exceed two (2) pages in length, entitled "Data Management Plan" immediately following the references and citations for the Science/Technical/Management section.

6.3.2 *Required Additional Section in Step-2 Proposal: Proposed Contribution to the Focused Science Team Effort*

Proposals to this program element must address the proposed contribution to the Focused Science Team effort in a separate section, not to exceed two (2) pages in length, entitled "Proposed Contribution to the Focused Science Team Effort", immediately following the Data Management Plan section of the proposal. Formatting requirements for this section are the same as for the Science/Technical/Management section. This section on Proposed Contribution to the Focused Science Team Effort does not count against the 15-page limit for the Science/Technical/Management section. Proposals that fail to address the proposed contribution to the Focused Science

Team effort may be declared noncompliant and will typically be returned without review or declined following review if the lack of this section is discovered during the evaluation process.

This section must summarize the following three topics:

- The relevance of the proposed study to the scientific objectives (Goals, Objectives, and Measures of Success) of the FST outlined in Sections 2.2, 3.2, 4.2, or 5.2;
- The potential contributions of the proposed study (Type of Investigation) to the Focused Science Team's effort outlined in Sections 2.3, 3.3, 4.3, or 5.3; and
- Metrics and milestones for determining the successful progress and outcome of the proposed research.

This summary must describe the goals of the proposed project and why they are aligned with the FST goals outlined in Sections 2.2, 3.2, 4.2, or 5.2. For proposals that address a Type of Investigation that is listed in Sections 2.3, 3.3, 4.3, or 5.3, this summary must also describe briefly how the proposed investigation addresses one or several of those investigations.

For proposals that address a type of investigation that is NOT listed in the FST description, the summary must briefly describe the proposed Type of Investigation and how the proposed investigation will meet the FST Goals and Measures of Success.

In addition, all proposers are expected to provide a set of metrics that they will use to identify progress toward their proposed goals. Proposers must also provide a set of milestones that should indicate the anticipated timing of the major achievements during the course of the proposed study. These metrics and milestones may change once the Focused Science Team is formed so the proposed metrics and milestones should be based on the proposed study as a stand-alone effort.

The review panel will only consider material in this section when the relevance of the proposal to the Focused Science Team effort is evaluated (see Section 6.3.4).

6.3.3 *Step-2 Compliance*

Non-compliant Step-2 proposals will be returned without review or may be declined if the non-compliance is found during the evaluation process. Step-2 proposals may be declared noncompliant if:

- The title has substantially changed from that of the Step-1 proposal;
- Investigators have changed since the Step-1 proposal without prior approval of the Program Officer;
- The science goals and objectives have substantially changed from that of the Step-1 proposal;
- The proposal has the same (or essentially the same) team and objectives as a Step-2 (full) proposal submitted to another Heliophysics program during the current ROSES announcement;
- The proposal violates the restrictions in Section 1.4 regarding use of data; or
- The proposal violates the formatting instructions in Section 6.3.1.

6.3.4 *Step-2 Evaluation Criteria*

Compliant proposals will be evaluated according to three main criteria: (1) Intrinsic Merit, (2) Potential Contribution to the Focused Science Team Effort (Relevance), and (3) Cost Reasonableness. The Data Management Plan will be evaluated as part of the Intrinsic Merit criterion. The Intrinsic Merit and Cost criteria will be evaluated primarily as specified in the *ROSES-2021 Summary of Solicitation* and defined in the *NASA Guidebook for Proposers*, but Relevance is handled differently. Clarifications and additions specific to this program element are listed below.

The evaluation of intrinsic merit will include the following:

- Scientific Merit: Compelling nature and scientific priority of the proposed investigation's science goals and objectives, including the importance of the problem within the broad field of Heliophysics; the unique value of the investigation to make scientific progress in the context of current understanding in the field, and the importance of carrying out the investigation now; and
- Technical Merit: Appropriateness and feasibility of the methodology, including the appropriateness of the selected data, models, and analysis for completing the investigation and the feasibility of the methodology for ensuring scientific progress.

The treatment of uncertainty will be evaluated as a methodology issue (intrinsic merit) and the review panel will assign a strength or weakness based on the treatment presented in the proposal. Proposers are free to choose any appropriate method of uncertainty analysis or validation of results, but it must be clearly addressed in the body of the proposal. Proposals that fail to address uncertainty will be assigned a Major Weakness in the evaluation and may be considered unselectable.

Intrinsic Merit and Relevance will be evaluated separately. Based on the above two factors (Scientific and Technical Merit), the evaluation will consider the overall potential science impact and probable success of the investigation and an adjectival grade for Intrinsic Merit will be assigned. The evaluation of the potential contribution to the Focused Science Team effort (Section 6.3.2) will serve as the Relevance evaluation and a separate adjectival grade for Relevance will be assigned.

The final adjectival grade assigned to the overall evaluation will be the lower of the two adjectival grades for Intrinsic Merit and Relevance.

Evaluation of Cost Reasonableness will include a comparison of the scope of the proposed study to the proposed resources (personnel-time allocated, necessary computer resources, etc.). The panel will provide feedback to SMD but will not assign a grade and this information will be considered by the Heliophysics selecting official during the selection process.

7. <u>Award Types</u>

The Heliophysics LWS Science program will only award funds through three vehicles: (1) grants, (2) interagency transfers, and (3) awards to NASA centers. This call will not award contracts, as it is not appropriate for the nature of the work. Please also see the *ROSES-2021 Summary of Solicitation,* Section II(a).

8. Available Funds

Given the strategic nature of LWS, and the fact that strategically feasible tasks require sufficient investment, it is anticipated that FST proposals will have annual budgets in the range of $180K - $250K per year. (This includes fully encumbered Civil Servant labor, where appropriate.) It is left to individual PIs to decide whether a strategically feasible award size could be achieved by increased collaborative efforts, greater time commitment of investigators, or a mix of the two. PIs should be cognizant, however, that verification of the level of effort versus the actual work proposed will be part of the review panel process. Given the submission of proposals of adequate number, merit, and range of investigative techniques, NASA anticipates forming teams of ~5 - 7 selections for each of the four FST topics.

Team Leader activities should not be included in the proposal budget. The Team Leader will receive up to an additional $25,000 per year to support his/her leader activities, and the Team Leader's budget will be revised during final award negotiations.

9. Summary of Key Information

Expected annual program budget for new awards	~ $5M, see also Section 8, above.
Number of new awards pending adequate proposals of merit	~ 20 – 28, see also Section 8, above.
Maximum duration of awards	4 years
Due date for Step-1 proposals	See Tables 2 and 3 of this ROSES NRA
Due date for Step-2 proposals	See Tables 2 and 3 of this ROSES NRA
Planning date for start of investigation	No earlier than 6 months after the Step-2 proposal due date.
Page limit for the central Science/Technical/Management section of proposal	15 pages; up to 2 extra pages each for separate section describing the Data Management Plan and the Proposed Contribution to the Focused Science Team Effort, and up to 1 extra page permitted for a separate section for proposers to be Team Leader of a Focused Science Team; see also Table 1 of the *ROSES-2021 Summary of Solicitation* and the *NASA Guidebook for Proposers*.
Relevance	Proposals that are relevant to the FSTs in this program element are, by definition, relevant to NASA. See Section 6.3.4 regarding evaluation criteria.
General information and overview of this solicitation	See the *ROSES-2021 Summary of Solicitation*.
General requirements for content of proposals	See Section 6.3 of this program element and Section IV and Table 1 of *the ROSES-2021 Summary of Solicitation*.
Detailed instructions for the submission of proposals	See NSPIRES Online Help, the *NASA Guidebook for Proposers* and Section IV(b) of *the ROSES Summary of Solicitation*.

Submission medium	Electronic proposal submission is required; no hard copy is permitted.
Web site for submission of proposals via NSPIRES	http://nspires.nasaprs.com/ (help desk available at nspires-help@nasaprs.com or (202) 479-9376)
Web site for submission of proposals via Grants.gov	http://grants.gov (help desk available at support@grants.gov or (800) 518-4726)
Funding opportunity number for downloading an application package from Grants.gov	NNH21ZDA001N-LWS
Points of contact concerning this program, both of whom share this postal address: Heliophysics Division Science Mission Directorate National Aeronautics and Space Administration Washington, DC 20546-0001	Simon Plunkett Telephone: (202) 358-2034 Email: simon.p.plunkett@nasa.gov Jeff Morrill Telephone: (202) 358-3744 Email: jeff.s.morrill@nasa.gov